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GEOMORPHOLOGY OF THE CENTRAL APPALACHIANS

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GEOMORPHOLOGY OF THE CENTRAL APPALACHIANS

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This guidebook is published under the auspices of the United States Geological Survey, but it is not a part of the Geological Survey's regular series of publications, and the opinions expressed in it and the use of nomenclature do not necessarily conform to Geological Survey usage. In spelling "peneplain" (rather than "peneplane") and in certain other details Geological Survey usage has been followed.

The guidebook was prepared by Douglas Johnson, of Columbia University, with the collaboration of Florence Bascom, of the United States Geological Survey, and Henry S. Sharp, of Denison University.

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HARPERS FERRY, WEST VIRGINIA

Photograph by Frank Smart, U. S. Geological Survey, before 1889.

GEOMORPHOLOGY OF THE CENTRAL APPALACHIANS

By Douglas Johnson, Florence Bascom, and Henry S. Sharp

INTRODUCTION

Twenty-five geomorphic provinces, each a unit containing within its boundaries areas of similar structure, origin, and topography, have been recognized within the United States. Parts of the New England Upland, the Triassic Lowland, the Newer Appalachian province, and the Piedmont and Blue Ridge provinces are to be studied in the course of this excursion. (See pl. 2.)

The number, origin, age, and correlation of peneplains within the area traversed present a problem concerning which there is still much difference of opinion. Although a larger number of erosion levels may be represented, the evolution and topography of the Appalachian region will be described with reference to the five most prominent peneplains and to altitudes above and below them. These peneplains, named in the order of their age, are the pre-Triassic, the Fall Zone (Jura-Cretaceous), the Schooley (Tertiary), the Harrisburg (probably late Tertiary), and the Somerville (possibly Pleistocene). The authors hope that this guidebook will be regarded, not as a statement of facts to be accepted without question, but merely as a guide to field discussions of problems encountered on the journey.

ACKNOWLEDGMENTS

In preparing this guidebook the authors have necessarily drawn heavily upon the studies of a very large number of workers in the broad field of Appalachian geology. It has seemed impracticable to cite authorities throughout the text, but the reader will understand that a guidebook such as this makes little pretense to originality. To Dr. Henry B. Kümmel, State geologist of New Jersey, and Dr. George H. Ashley, State geologist of Pennsylvania, who traversed with us the portions of the route in their respective States, we are indebted for invaluable aid at many points. Dr. Bradford Willard, of the Pennsylvania Geological Survey, at our request made additional

field studies in the vicinity of Godfrey Ridge and prepared the geologic map and section for the Delaware Water Gap-Stroudsburg area. The diagrams illustrating the text were drawn by Dr. Erwin J. Raisz, of Columbia University, on the basis of rough pencil sketches prepared by the senior author.

GEOMORPHIC PROVINCES

The geomorphic provinces to be visited are briefly described in the following paragraphs. Further details concerning each province will be found in the annotated itinerary. The reader will be aided by reference to Plate 2 and Figures 1–9.

NEW ENGLAND UPLAND

Extent and boundaries.—Practically the entire area of the New England States is included within the New England Upland, which also extends northward into Nova Scotia, New Brunswick, and Quebec. In addition two long projections reach southwestward—one called the Reading prong, extending through New Jersey to Reading, Pennsylvania, and the other, the Manhattan prong, to New York City. Owing to the greater resistance of its rocks the province in general stands higher than its neighbors, and the boundaries are definite. On the east and south they are the waters of the Atlantic Ocean and Long Island Sound. On the north and west the New England Upland is limited by the St. Lawrence Lowland and the Great Valley, respectively. This boundary is clearly defined and in places follows a fault-line scarp.

Between the Manhattan and Reading prongs is the north end of the Triassic Lowland. The western boundary of the Manhattan prong is formed by the Hudson River, which has resurrected the erosional surface on which the Triassic sediments were deposited. Throughout its length the eastern boundary of the Reading prong is a fault-line scarp following the line along which Triassic sediments were downfaulted into older rocks. The development of these boundaries is shown in Figures 1–9. These sections portray the evolution of the Appalachians.

Rocks, structure, and topography.—The upland character of the province is due to the greater resistance of its rocks, which are predominantly pre-Cambrian metamorphic and intrusive igneous rocks, together with highly metamorphosed lower Paleozoic sediments. Many areas of infaulted or infolded younger sediments of lesser resistance have been eroded to form lowlands, the floors of which may lie several hundred feet below the general upland surface. In the Reading prong these local lowlands gen-

FIGURE 1.—Rejuvenated Appalachians in post-Newark time

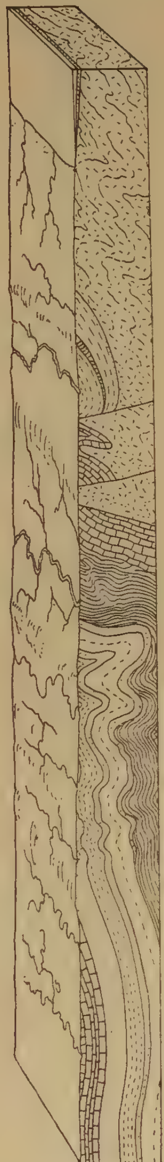

FIGURE 2.—The Fall Zone peneplain

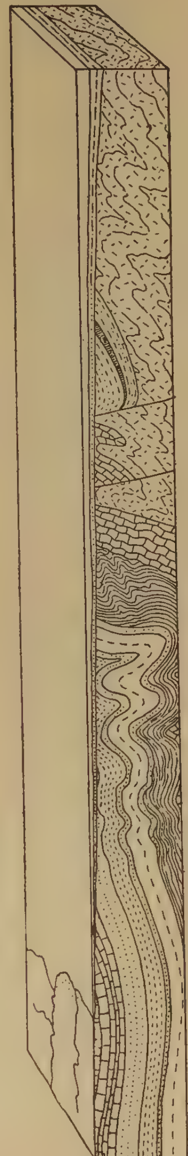

FIGURE 3.—Encroachment of Cretaceous sea and deposition of Coastal Plain beds

FIGURE 4.—Arching of Fall Zone peneplain and its Coastal Plain cover; regional superposition of southeastward-flowing streams

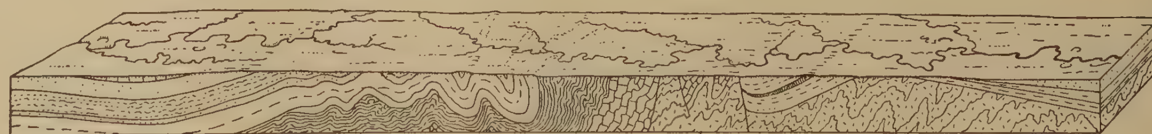

FIGURE 5.—The Schooley peneplain

FIGURE 6.—Arching of Schooley peneplain

FIGURE 7.—Dissection of Schooley peneplain and development of Harrisburg peneplain on belts of nonresistant rock

FIGURE 8.—Uplift and dissection of Harrisburg peneplain and development of Somerville peneplain on the weakest rock belts

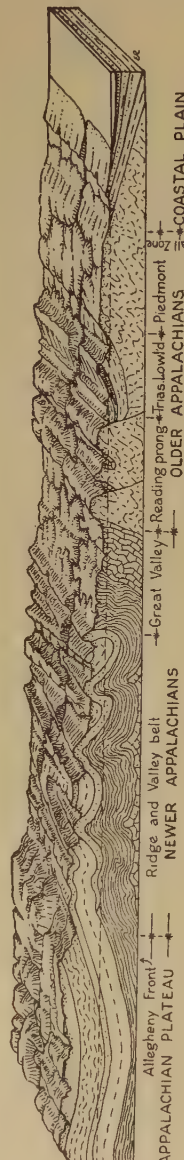

FIGURE 9.—Uplift and dissection of Somerville peneplain to give present conditions

NOTE.—Figures 1 to 9 are reproduced by permission of the Columbia University Press.

erally are eroded on the Kittatinny limestone (Cambrian and Lower Ordovician) and the Martinsburg shale (Ordovician). A Cambrian sandstone underlies the Kittatinny limestone, but its resistance is in places so great that it rises to the general upland level maintained by the pre-Cambrian gneisses. In New York City the pre-Cambrian of the Manhattan prong includes the Fordham gneiss, the Inwood limestone (marble), and the Manhattan schist. Columbia University and the larger part of Manhattan are built on the Manhattan schist.

The structural trends are usually north-south or northeast-southwest. This is true of the foliation of the pre-Cambrian and of the folds and faults of the younger rocks, although large igneous masses occur in which no structural orientation is noticeable. Many subsequent streams follow the structural trends and over much of the territory cause a marked northerly or northeasterly alinement of ridges and valleys. The stream courses have been extensively modified by glaciation, which has affected all parts of the province except the southern part of the Reading prong.

The general upland level slopes southeastward about 10 or 15 feet to the mile (2 to 3 meters to the kilometer). This is the Schooley or Upland peneplain, of probable Tertiary age. Above this surface in New England single peaks and entire ranges occur as monadnocks, but no conspicuous monadnocks are found on the Reading or Manhattan prongs. Along a belt about 10 or 15 miles (16 to 24 kilometers) broad in southern Connecticut the southward slope of the upland increases to 50 feet to the mile (10 meters to the kilometer). This surface of greater slope is called the Fall Zone peneplain and was probably formed during Jurassic and early Cretaceous time. The break between it and the Schooley surface is believed to have caused the fall line, which in general follows the inland boundary of the Coastal Plain of the eastern United States. The upland surface is maturely dissected by streams flowing in submature or youthful valleys. Broad lowlands which may represent one or more peneplains younger than the Schooley are found several hundred feet below the upland level. The shore line of much of New England is deeply embayed through the partial submergence of valleys and lowlands.

TRIASSIC LOWLAND

Extent and boundaries.—The region known as the Triassic Lowland is often considered part of the Piedmont province, which contains numerous smaller areas of Triassic rocks. It has been called the Piedmont Lowland. This is by far the largest area of Triassic rocks in eastern North America, and its extent and

geomorphic unity seem to justify its treatment as a separate province. It extends from southeastern New York to north-central Virginia, but in very few places in all its length of about 300 miles (480 kilometers) does it attain a width of 30 miles (50 kilometers). The northwestern boundary is probably everywhere a fault-line scarp. In New Jersey, between the lowland and the Reading prong, the scarp faces southeastward and is resequent; in Pennsylvania it faces the Great Valley and is obsequent; from southern Pennsylvania to Virginia the boundary between the Blue Ridge province and the Triassic Lowland is again a resequent fault-line scarp similar to that in New Jersey. The southeastern boundary in the north is marked by the Hudson River, which has removed the Triassic sediments from the pre-Triassic basement. From the mouth of the Hudson to Trenton, New Jersey, the boundary is not obvious topographically but follows the contact between the Triassic and the overlying Coastal Plain sediments. From Trenton to the end of the province in Virginia the boundary between the Triassic Lowland and the Trenton prong of the Piedmont is similar in origin to that followed by the Hudson River. It is noteworthy that both ends of the province are embraced between prongs of crystalline rock—in the north the Reading and Manhattan prongs, in the south the Carlisle and Trenton prongs. The boundaries are in most places well defined, both geologically and topographically.

Rocks, structure, and topography.—The sedimentary rocks of this province (called the Newark group) are almost entirely clastic and of continental origin and are typically red sandy shales and red sandstones. The entire section is said to be over 20,000 feet (6,100 meters) thick, but the presence of numerous strike faults makes the true thickness difficult of determination. The monotony of the Triassic sediments is varied by the presence of numerous dikes, sills, necks, and sheets of basic igneous rocks, often designated simply trap. In New Jersey four great sheets of trap occur. Of these the lowest (the Palisade diabase) is intrusive and in places reaches a thickness of 1,000 feet (300 meters). Above the Palisade diabase and separated from it and one another by several hundred feet of intervening Triassic shales are three extrusive basalt flows. These form the Watchung Mountains and from bottom to top are 650, 850, and 350 feet (200, 260, and 110 meters) thick. In the Gettysburg area is found a sill 1,800 feet (550 meters) thick, or 800 feet (250 meters) thicker than the Palisade sheet, although it is not so prominent topographically.

Both during and after the accumulation of the sediments and igneous materials of the Newark group pronounced normal faulting took place along the northwest side of the basin. As a

result the beds were lowered in that direction and to-day usually show a dip of 10°–20° NW. Except for some local warps this homoclinal dip is general within the province and governs the topography, the lowland surface consisting in general of series of low ridges and shallow valleys, most of which trend northeastward. Faulting within the basin, probably contemporaneous with the major displacement along the northwest border, has caused slight offsets of the trap ridges.

Whether the lowland surface should be correlated in part with the Harrisburg and in part with the Somerville peneplain, or whether it represents one or more independent erosion levels, is not clear. The surface is broken by numerous monadnocks indicating outcrops of trap or resistant sandstone or conglomerate. The tops of some of the monadnocks—for example, part of the Palisades ridge—preserve the Schooley level; but most of them have been reduced somewhat below it. The homoclinal dip has caused most of the hills to be more scarplike toward the southeast, but exceptions due to local warping are found. Glacial scour has removed preglacial soil and talus and has freshened and steepened the scarp faces. Outside New Jersey the Triassic Lowland has not been glaciated, and the soil is largely residual, derived from the decay of the red shales and the trap. Here the ridges are more rounded and subdued, and bare scarps like the Palisades are rare.

NEWER APPALACHIAN PROVINCE[1]

Extent and boundaries.—The Newer Appalachian province is over 1,000 miles (1,600 kilometers) long but in few places attains a width of 80 miles (130 kilometers). It can readily be divided longitudinally into a northwestern section, in which high ridges alternate with valleys of moderate width (the "Ridge and Valley" section), and a broad southeastern lowland section (the "Great Valley"). This division is more or less apparent throughout the length of the province.

Except for a short distance in New York the entire northwestern boundary of the province is an erosional escarpment formed on gently dipping or horizontal sediments of the Appa-

[1] The terms "Newer Appalachians" and "Older Appalachians" as used in this guidebook refer merely to the two extensive provinces in the first of which the rocks involved are for the most part of younger geologic age (Paleozoic) and in the second of which the rocks are for the most part older (pre-Cambrian). It is recognized that these terms are not wholly satisfactory, but they are so well established in the literature that the usage is followed here, with the clear understanding that the terms "newer" and "older" have no reference either to the relative times of mountain building in the two areas or to stages of topographic development in either.

lachian Plateau. The eastern and southeastern boundaries, where formed by the New England Upland and the Triassic Lowland, are described above, in the sections devoted to those provinces. From southern Pennsylvania to Alabama the southeastern boundary is formed by the resistant rocks of the Blue Ridge, towering above the Great Valley. This boundary is erosional in origin, weaker Paleozoic sediments having been stripped from the pre-Cambrian surface (in some places from resistant Cambrain quartzites) on which they were deposited. In other localities the contact of weak Paleozoic sediments with resistant crystalline rocks takes place along a low-angle thrust fault, and erosion has lowered the sediments northwest of the fracture plane. The origin of these boundaries is illustrated in Figures 1–9.

Rocks, structure, and topography.—The rocks of the province are Paleozoic sediments ranging in age from Cambrian to Pennsylvanian. Their resistance to erosion varies greatly and has a very important effect upon the topography. The broad lowland composing the Great Valley is due to the weakness of the Cambro-Ordovician limestones (Kittatinny and other formations) and Ordovician shales (Martinsburg). The ridges of the Ridge and Valley belt are composed of very resistant middle and upper Paleozoic sandstones and conglomerates, particularly the Tuscarora quartzite and conglomerate (Silurian), the Pocono sandstone (Mississippian), and the Pottsville conglomerate (Pennsylvanian).

At the end of Paleozoic time the sediments in the Newer Appalachian province were subjected to strong pressure from the southeast and folded into great anticlines and synclines, in places overturned toward the northwest. Reverse faults were also commonly developed in the zone of greatest pressure, while farther west, away from the source of pressure, the horizontal attitude of the beds was scarcely disturbed. The region of undisturbed rocks to-day forms the Appalachian Plateau; the folded area has become the Newer Appalachians. In the latter province the structural trends are northeasterly, and owing to the remarkable development of subsequent streams the topographic features trend in the same direction. The sandstone ridges in places preserve the level of the Schooley peneplain, and the Martinsburg and other shales show the best examples of the Harrisburg surface. On the Kittatinny and other limestones the younger and lower Somerville surface is usually found and in places is coextensive with those limestones. Local erosion levels may occur below the Somerville.

The drainage evolution of the Ridge and Valley belt is complex, as the mountains are not in their first cycle of erosion.

The chief transverse streams in the north, including the Delaware, Lehigh, Schuylkill, Susquehanna, and Potomac Rivers, are believed to have originally been consequent streams flowing southeastward on the Coastal Plain cover of the Fall Zone peneplain, no traces of which remain in the province. These streams were superimposed on the underlying base-leveled folds, and now flow through the ridges in water gaps famous for their natural beauty. Numerous well-developed wind gaps indicate that many other superimposed consequents were captured by subsequents growing headward along belts of weak rock. The subsequent streams have many obsequent and resequent tributaries, which help to emphasize the very marked trellis pattern of the drainage of this province.

The even surface and rich limestone soils of the Great Valley have made it in the past a popular pathway of migration and warfare and to-day one of the richest farming regions of the United States. The Appalachian Mountains long acted as a formidable barrier to the westward migration of the English and Dutch speaking settlers of the Atlantic coast and still retain much of their rugged wildness.

PIEDMONT AND BLUE RIDGE PROVINCES (OLDER APPALACHIANS) [3]

Extent and boundaries.—Although distinctly different in topography and altitude the Piedmont and Blue Ridge provinces are so closely related in origin that it is convenient to treat them together. The Blue Ridge rises in southern Pennsylvania as the Carlisle prong and continues southwestward in accordance with the general trend of the Appalachian provinces to northern Georgia. Marked topographic breaks separate it from the Great Valley section of the Newer Appalachian province on the northwest and the much lower Piedmont province on the southeast. The boundary between the Blue Ridge and the Great Valley is due to erosion, which has removed the less resistant Paleozoic sediments from the crystalline basement on which they were deposited, from resistant Cambrian sandstones where these maintain the high level of the crystalline rocks, or from a fault contact (in places a low-angle thrust fault which carried the crystalline rocks northwestward over parts of the Paleozoic sediments). The exact origin of the escarpment between the Blue Ridge and the Piedmont is still in doubt.

The north end of the Piedmont rises at Trenton, New Jersey, from which it receives the name Trenton prong, and the province extends to central Alabama. Throughout its length the

[3] See footnote 1, p. 8.

southeastern boundary follows the contact between the Coastal Plain sediments and the crystalline rocks of the Piedmont, a line which for reasons not fully understood is paralleled more or less closely for miles by parts of the Delaware, Susquehanna, and Potomac Rivers. Between the Carlisle and Trenton prongs is the southern part of the Triassic Lowland. (See p. 6.) The fall line of the eastern United States approximately follows the boundary between the Piedmont and the Coastal Plain.

Rocks, structure, and topography.—The rocks and structure of these provinces are in many ways similar to those of the New England Upland. Both the Piedmont and the Blue Ridge are predominantly composed of pre-Cambrian metamorphic rocks of highly complex structure and origin, with interbedded igneous rocks and intrusive granites and gabbros. In the Piedmont several small areas of infaulted Triassic beds occur, and in both provinces closely folded bodies of Paleozoic rocks are included in the older rock. There is apparently no difference in the resistance of the rocks of the two provinces, as might be thought from their great difference in altitude. The structural trends are northeasterly, and in some localities poor examples of trellis drainage pattern may be found, although the dendritic pattern is probably more common and is excellently shown in much of the Piedmont.

The Blue Ridge province, which takes its name from the Blue Ridge, in Virginia, typically consists of several individual ranges or ridges, which in the north may average 5 to 10 miles (8 to 16 kilometers) in width; but in North Carolina the Blue Ridge province reaches a width of 80 miles (130 kilometers). The Schooley peneplain appears to be well developed in parts of the province, but the age and correlation of erosion surfaces is still in doubt. There are many monadnocks and monadnock masses.

The surface of the Piedmont Upland is from less than 1,000 feet (300 meters) to more than 2,500 feet (760 meters) below the level of the Schooley peneplain in the Blue Ridge. In Virginia and North Carolina the Piedmont peneplain has been maturely dissected, but the sky line in all directions is still remarkably even. Only here and there is it broken by monadnocks. The origin and age of the Piedmont are intimately connected with the origin of the Blue Ridge escarpment, which divides the lower Piedmont surface from the higher Blue Ridge province. These questions have for a long time been subject to debate, and the following hypotheses of origin for the escarpment have been considered:

1. The escarpment is due to differential erosion of regions of varying rock resistance.

2. The escarpment is a sea cliff produced by marine erosion.
3. The escarpment is either a fault scarp or a fault-line scarp.
4. The escarpment originated by the warping of a single erosion surface.
5. The escarpment is the break between two normal peneplains of the same age, where these meet at the heads of drainage systems having very different lengths.
6. The escarpment is the break between two peneplains of different age.

Whatever hypothesis of origin is accepted, there remains the problem of variations in level on the Piedmont surface, interpreted by some observers as representing marine terraces, either produced as the surface was being formed, by wave action, or etched on an earlier surface of nonmarine origin.

The Piedmont surface as a whole slopes seaward a few feet to the mile, but near its eastern margin the presence of the resurrected older Fall Zone surface causes a break in the slope similar to that between the Schooley and Fall Zone peneplains in New England, where the latter also slopes more steeply seaward. The presence of water power and the interruption to stream navigation near the break between the two peneplains have resulted in the location of many of the most important industrial centers of the South.

Neither of these provinces was affected by continental glaciation, and in spite of high altitudes in the Blue Ridge province no evidences of local glaciation have been discovered. The soil is largely residual and of great depth; rock outcrops are relatively less abundant in the Piedmont, which is characterized by red clay soils.

ITINERARY

First day.—New York City, New York, to Caldwell, New Jersey (about 60 miles, or 100 kilometers)

Partial section across Triassic Lowland. Study of intersecting Fall Zone and Schooley peneplains, wind gaps and water gaps marking ancient Hudson drainage, and glacial Lake Passaic.

1.[3] *Manhattan Island, New York City.*—Manhattan Island forms the tip of the southerly projection of the New England Upland known as the Manhattan prong. It is composed of crystalline rock, mainly the resistant Manhattan schist and weaker crystalline limestone, both of pre-Cambrian age. Along Riverside Drive fresh outcrops of the Manhattan schist may be observed in Riverside Park.

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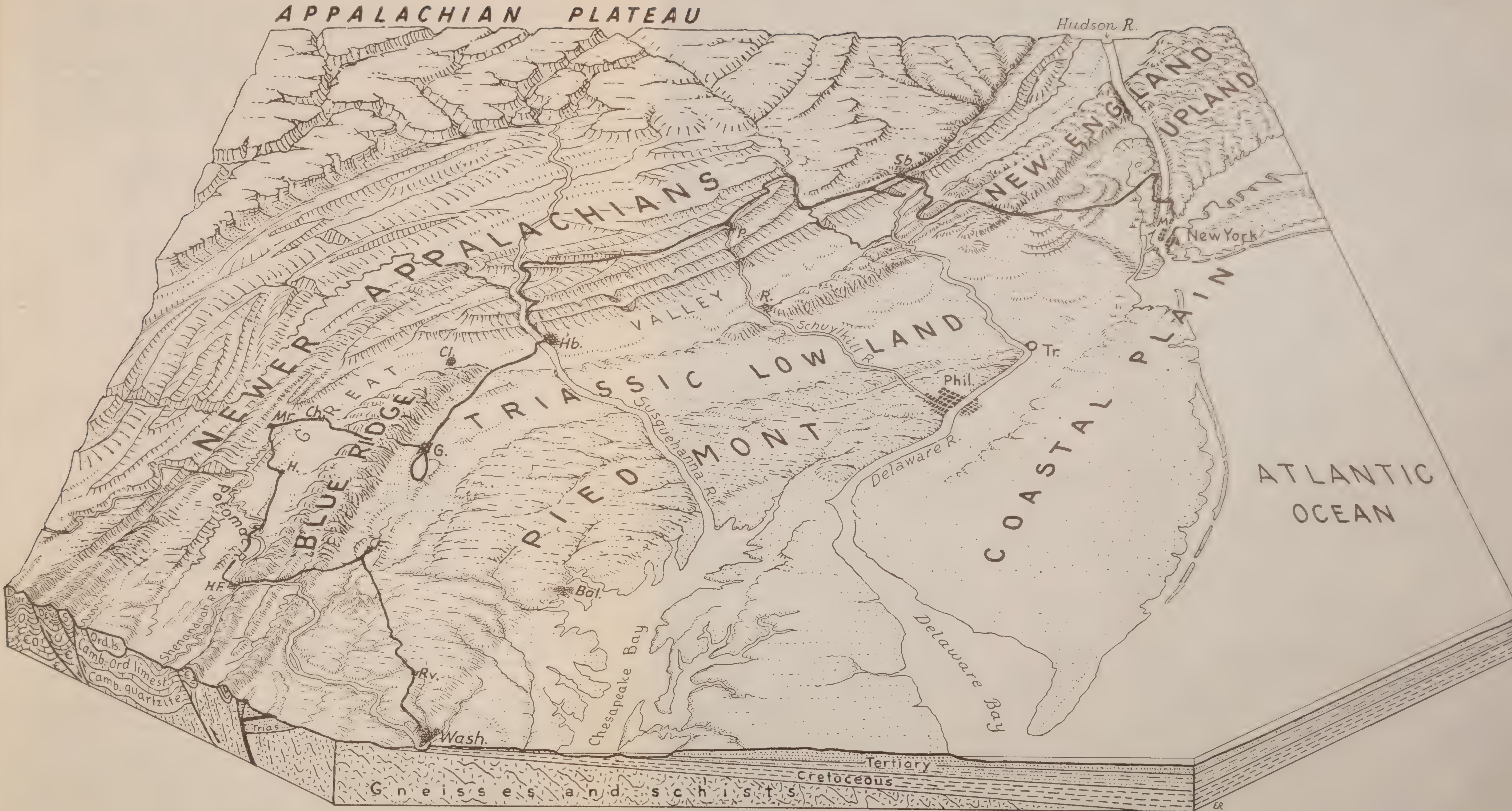
[3] Numbers refer to numbered points on the route maps (figs. 10, 14, 20, 23, 25, 28).



BLOCK DIAGRAM SHOWING GEOMORPHIC PROVINCES VISITED AND ROUTE FOLLOWED

M., Manhattan; Sb., Stroudsburg; P., Pottsville; R., Reading; Hb., Harrisburg; Cl., Carlisle; G., Gettysburg; Ch., Chambersburg; Mr., Mercersburg; H., Hagerstown; HF., Harpers Ferry; F., Frederick; Rv., Rockville; Wash., Washington; Bal., Baltimore; Phil., Philadelphia; Tr., Trenton.

2. *The Hudson River.*—At this point and in fact as far up as Troy, New York, some 150 miles (240 kilometers) from the sea, the tides are perceptible and the Hudson is a drowned river, one of the many so characteristic of the shore line of submergence of the northeastern United States.

The Hudson opposite New York City and northward for 40 miles (65 kilometers) is undoubtedly a subsequent stream. By

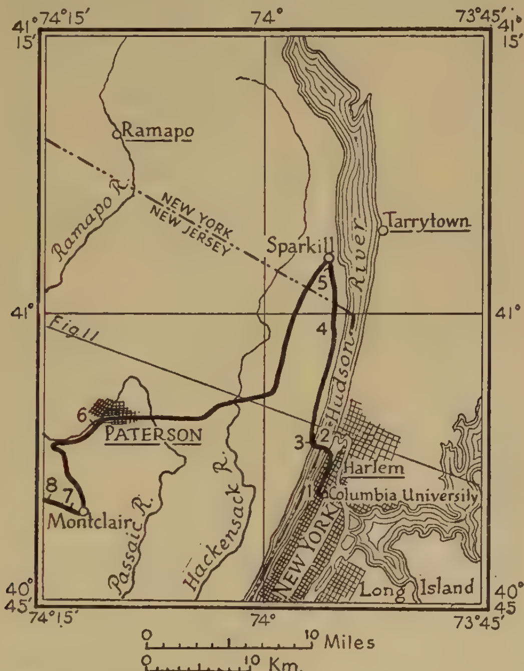


FIGURE 10.—Route map, first day. In this and succeeding route maps the rectangles correspond to topographic maps published by the United States Geological Survey, and the name of each map is underlined. The location of geologic sections shown in other figures is also indicated

some the line of weakness followed by the river has been attributed to the crush zone of a fault, or to a belt of pre-Cambrian limestone; but it seems more probable that the stream has eroded its valley in weak Triassic shales lying, as shown in Figure 11, between the resistant crystalline rocks of the New England Upland on the east and the resistant igneous rock of the Palisades on the west. If so, the river must have gained its course when

flowing on the erosional surface whose remnants can be seen in the level sky line of the Palisades.

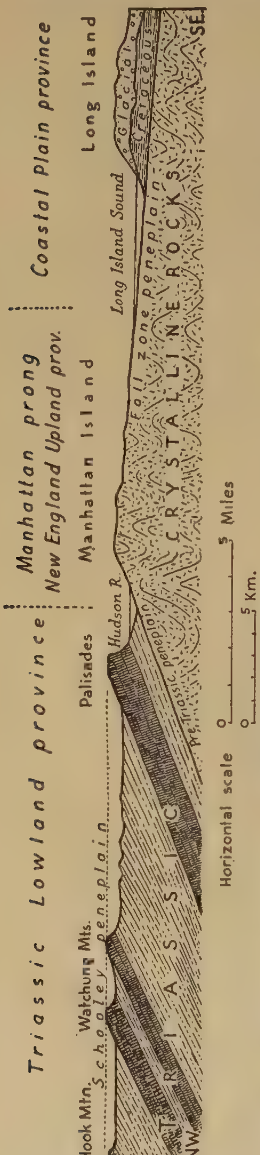


FIGURE 11.—Generalized section from the Long Island cuesta northwestward across Manhattan to Hook Mountain. The Fall Zone and Schooley peneplains intersect at a low angle, and the relation of the Palisades crest to this angle has not been determined in the area visited

3. *The Palisades.*—The Hudson River forms the boundary between two physiographic provinces, and immediately after crossing it by the longest single-span bridge in the world we enter the State of New Jersey and the Triassic Lowland, the general features of which have been described in the preceding pages.

Near the west end of the bridge the contact between the Palisade diabase and the underlying shale may be observed. The shales are baked and hardened, and large masses are rifted loose and raised into the intrusive. The diabase was intruded as a sheet (300 to 1,000 feet (90 to 300 meters) thick) near the bottom of the upper Triassic Newark group. In cooling, columnar jointing developed on a large scale. To the early settlers of New Amsterdam (New York) these columns resembled a great fence of stakes; hence the name "Palisades."

In the face of the Palisades escarpment may be seen, even from a distance, a zone of pronounced weathering. Examination shows that this zone is especially rich in olivine crystals. It would seem that when the great intrusive mass was beginning to cool and the lower zone in contact with the shales had become too solid or pasty for minerals to sink through it, olivine crystals forming in the still molten mass in the center of the intrusion settled until checked by the pasty zone. When the whole mass was chilled and later exposed to erosion, the olivine zone, near but not quite at the

bottom of the sheet, succumbed to weathering more rapidly than the remainder of the rock. This weathering has in places produced a distinct bench on the face of the scarp.

The summit level of the Palisades is a broad and notably flat upland surface which is very largely occupied by villages and towns. Outcrops of the fresh diabase are fairly common, and as the sheet composed of this resistant rock dips westward about 10°, it becomes apparent why this flat upland neatly beveling the structure has long been recognized as a peneplain. The surface is usually correlated with that on Schooley Mountain, in the New Jersey Highlands, and called the Schooley peneplain. Its southerly extension may, however, coincide with the Fall Zone peneplain.

The bare upper face of the Palisades, in which the columnar structure is so well exposed, is a feature peculiar to the glaciated portion of the Triassic Lowland. South of the glacial limit the scarp faces are more subdued, largely covered with talus or soil, and in most places obscured by forest. It would appear that in the glaciated area ice had removed soil and talus and possibly steepened the cliff face by moderate glacial erosion. Glacial striae and the distribution of trap boulders over the Manhattan prong indicate that the last ice movement was here toward the southeast, obliquely across the Hudson trench; but this is compatible with simultaneous or earlier ice movement southward in the trench itself.

4. *Lookout Point, north of Alpine.*—From this point three physiographic provinces are under observation. Close at hand the tilted columns of the Triassic Lowland diabase suggest that the contact plane to which they are normal dips 10°–20° W. The surface on which we stand is more nearly horizontal and is recognized as the erosion plane beveling the tilted trap sheet. Across the river either the Schooley or Fall Zone peneplain may be seen descending southeastward across the Manhattan prong of the New England Upland, and beyond, on a clear day, is visible the cuesta of the Atlantic Coastal Plain, which, together with its heavy mantle of glacial deposits, forms Long Island. Toward the northeast yet another erosion plane is suggested by the succession of crystalline hills descending gently westward into the Hudson. This is the pre-Triassic peneplain, resurrected by the removal of weak westward-dipping Triassic sandstones and shales to form the subsequent valley now occupied by the drowned Hudson River. The crest of the upland across the river thus marks the intersection of the pre-Triassic peneplain with a later peneplain of Cretaceous or Tertiary age.

5. *Sparkill Gap.*—This remarkable sag in the Palisades, 300 feet (90 meters) or more below the crest line and nearly 2 miles (3.2 kilometers) broad, appears to be an old water gap which was changed to a wind gap by diversion of the large stream that carved it and then trenched, probably in glacial or postglacial time, by a small brook called the Sparkill. It is believed that the Hudson River once crossed the Palisades through this gap, flowing southwestward to the gaps through the Watchung Mountains at Paterson. (See fig. 12.) Subsequent erosion of the shale belt between the Palisade diabase and the Manhattan schist provided a more direct route on weak rocks to the sea, into which the Hudson was diverted to give the present arrangement of the drainage.

Turning southwest from Sparkill Gap obliquely across the strike of the Triassic beds (which here trend N. 25° E.), we note the succession of low ridges and swales developed by stream erosion on the northwestward-dipping sandstones and shales.

6. *Paterson Gap.*—Passing through Paterson, the road rises on the slope of First Watchung Mountain. This ridge is the first of three mountain ridges formed by extrusive flows of trap. More resistant than the Triassic sediments, the flows have produced monoclinal mountains with steep eastward and gentle westward slopes, similar in form to the Palisades. Different sections of the mountain crest are fairly accordant in altitude, and in places the top is broad and flat, like the top of the Palisades, but is considerably higher. The Watchung upland is correlated with the Schooley peneplain, which here stands about 600 feet (180 meters) above sea level and is believed to slope southeastward.

Paterson Gap, cut deeply into First Watchung Mountain, is nearly 2 miles (3.2 kilometers) broad, and its floor is slightly lower than that of Sparkill Gap. It is believed to have been carved by a large river (the Hudson) flowing from northeast to southwest across the strike. Toward the southwest may be observed a similar broad gap in Second Watchung Mountain, and yet another is found in the third extrusive flow. Thus we have four unusually broad gaps, cut across four successive trap ridges, alined in a northeast-southwest direction, and all apparently cut by a stream larger than the present drainage lines and flowing in a different direction. These features have been interpreted as the result of superposition of a large subsequent river from its former position on an overlying Coastal Plain cover, as shown in Figure 13.

7. *Montclair wind gap.*—The bottom of the wind gap at Montclair is 509 feet (155 meters) above sea level and about 100 feet (30 meters) below the mountain top and is believed to mark one

FIGURE 12.—Hypothetical course of the Hudson River in Schooley time, according to the theory of superposed subsequent drainage. Reproduced by permission of Columbia University Press

point in the course of a stream that formerly flowed northwestward across the trap ridges to join the master stream farther west. (See fig. 13.) Subsequent streams developing on the weak sandstones and shales diverted the transverse stream to more favorable courses parallel to the structure, leaving wind gaps in both First and Second Watchung Mountains.

8. *Second Watchung Mountain and Caldwell wind gap.*—The structure and origin of Second Watchung Mountain are very similar to those of First Mountain, but in accordance with the

FIGURE 13.—Inferred cuesta and lowland topography above the Watchung trap sheets in Schooley time. A, Earlier stage of erosion; B, later stage of erosion; C, possible consequent stream flowing southeast; R, resequent streams flowing southeast; O, obsequent streams flowing northwest; S, subsequent streams draining broad lowlands; W_1, W_2, First and Second Watchung Mountain trap sheets. Reproduced by permission of Columbia University Press

slope of the Schooley peneplain the crest is in general somewhat higher. Many wind gaps cut the ridge, and we pass through one of the largest, which is nearly 200 feet (60 meters) below the general level of the mountain, or 40 feet (12 meters) lower than the Montclair gap.

9. *Caldwell.*—Second Watchung Mountain has a double crest throughout much of its length. This could readily be explained if the ridge consisted of two principal flows separated by a thin bed of weaker sandstones or shales. In the northern part of Caldwell an exposure of Triassic beds between lava flows indicates that the relation suggested does exist.

10. *Monomonock Inn.*—From the veranda of the Monomonock Inn, at the west edge of Caldwell, we may look westward across the floor of glacial Lake Passaic. Thus far the route has been entirely within the limits of Wisconsin glaciation, of which the formation of this lake was an interesting episode. The area of Newark sediments, bounded by the Highlands and Second Watchung Mountain, formed as now a topographic basin before the advance of the ice sheet. This basin was drained by streams tributary to the superposed subsequent (fig. 12), which flowed outward at the Short Hills and Millburn gaps, farther south. When the ice occupied the gap at Short Hills a small lake formed and drained southwestward through a low col at the end of the basin. When the ice retreated the Short Hills outlet was left filled with moraine and so was still effectively dammed. As the ice continued to retreat, the lake grew constantly larger until the Paterson gap was free and the water escaped.

The Monomonock Inn is situated on the western slope of Second Watchung Mountain, on shore deposits of Lake Passaic. From the porch of the inn, looking across the lowland once occupied by the lake, we see in the distance the rather even sky line of the New Jersey Highlands. These mountains, composed largely of resistant crystalline rock, are a southwesterly projection of the New England Upland reaching to Reading, Pennsylvania, and often called the Reading prong. In general the summit altitudes range from 800 to 1,200 feet (240 to 370 meters) above sea level, growing higher toward the northwest.

The Reading prong forms the western boundary of the Triassic Lowland, and the dissected escarpment facing us follows the line of a fault along which the weak Triassic sediments have been dropped into contact with the resistant pre-Cambrian crystalline rocks. The escarpment is not a fault scarp, due directly to movement, but a fault-line scarp. After the faulting erosion lowered the region to the level of the Fall Zone peneplain and later to the level of the Schooley peneplain seen in the even sky line. The Triassic and pre-Cambrian rocks were eroded to about the same level, and the topographic expression caused by faulting was largely removed. When the Schooley cycle ended with uplift, the rejuvenated streams removed the weaker sediments more rapidly, thus exposing the fault-line scarp which we see to-day. It is about 500 feet (150 meters) high.

The lower summit, which is visible between us and the Highlands is Hook Mountain, formed by the third of the great extrusive flows through which we pass. It is only one-half as high as the adjacent Reading prong, presumably because formed of a thin sheet.

Second day.—Caldwell, New Jersey, to Stroudsburg, Pennsylvania (about 80 miles, or 130 kilometers)

Luncheon at Washington, New Jersey. Section from Triassic Lowland across crystalline highlands (Reading prong of New England Upland) to marginal folds of Newer Appalachians. Study of warped trap ridge, fault-line scarps and subsequent valleys, Schooley and Harrisburg peneplains, water gaps and wind gaps of ancient southeastward-flowing streams, and Appalachian folds.

11. *Hook Mountain.*—The name Hook Mountain has reference to the extremely curved trend which, as shown on the Morristown topographic map, is reversed in the north by Packanack Mountain. This curved trend is due to the folding of the westward-dipping trap sheet into an anticline at Hook Mountain and a syncline at Packanack Mountain, followed by planation to give the curved outcrops. The flow is found

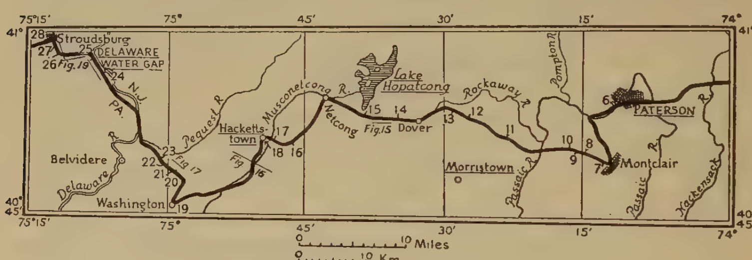


Figure 14.—Route map, second day

farther south in Riker Hill and Long Hill, and the lack of continuity between the various ridges is believed to result from superposition across the beveled edge of the flow of the same large river (the Hudson) which carved the Sparkill and Paterson gaps. Well records show the trap to be continuous under the meadows of the gap south of Riker Hill, and its presence under the marshes south of Hook Mountain is inferred.

12. *Parsippany.*—Within a short distance the road enters the terminal moraine of the Wisconsin glaciation, very near the western edge of Lake Passaic. The boulders composed of quartz pebbles in a dark-red matrix represent the Skunnemunk conglomerate, of Devonian age, transported here from outcrops in the Highlands.

13. *Denville.*—At Denville we are well within the crystalline area, although the passage from the lowland has been scarcely perceptible, because we enter the Highlands by a broad valley believed to represent the preglacial course of the Rockaway

River. The mountains to the right and left consist of gneisses of pre-Cambrian age, with foliation striking northeast, more or less parallel with the larger structural features of the region. The road follows the valley of the Rockaway River through Dover to Mine Hill.

14. *Mine Hill.*—From this point westward across the intervening German Valley may be seen the very even sky line of the Schooley peneplain forming the upland of Schooley Mountain, the type locality of this erosion surface.

German Valley is one of the many northeastward-trending valleys developed in the crystalline upland by erosion of infolded or infaulted Paleozoic sediments.

When the Schooley cycle was completed, these areas of weaker rock were presumably near the same level as the mountain tops composed of gneiss and were preserved because of their position below the plane of Schooley erosion. When regional uplift occurred, the sediments, largely limestones and shales, were rapidly removed, and fault-line scarps, similar in origin to that discussed under stop 10, were formed. The western wall of German Valley is such a scarp; the eastern wall corresponds to the downwarped resurrected erosional surface on which the Paleozoic sediments were deposited. A structure section of this valley is shown in Figure 15.

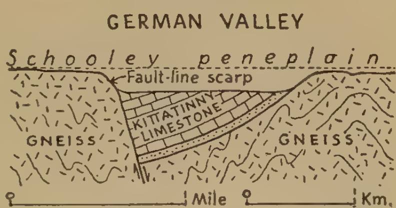


FIGURE 15.—Structure section of German Valley

15. *Ledgewood.*—After leaving Mine Hill and crossing the rather flat valley floor we reach Ledgewood, where the route traverses the fault and again enters the crystalline rocks. Passing Netcong, the route turns southwest past Budd Lake.

16. *Schooley Mountain.*—A few miles beyond Budd Lake the road ascends to the rolling upland of Schooley Mountain, which is here about 1,100 feet (335 meters) above sea level. The type locality of the Schooley peneplain exhibits the general accordance of hilltop levels combined with the moderate degree of relief to be expected in a peneplain. The present rolling character of the topography is due in part to post-Schooley erosion, and the scenery is similar to that in many parts of New England.

17. *Musconetcong Valley.*—The eastern and western walls of Musconetcong Valley are fault-line scarps. The valley floor has been eroded on weak Paleozoic sediments faulted below the

level of Schooley erosion. The form is that of a graben (fig. 16), but, as in German Valley, the depression is not due directly to faulting but to erosion of much later date.

18. *Hackettstown.*—Toward the north, just before reaching Hackettstown, the terminal moraine of the Wisconsin glaciation may be seen at a distance of about 1 mile (1.6 kilometers). West of the town can be had views of the morainic hills and of the even sky line of the peneplain on Schooley Mountain.

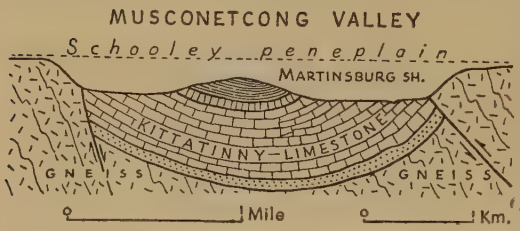


FIGURE 16.—Structure section of Musconetcong Valley

From Hackettstown the route turns south and follows the Musconetcong River along the southeast side of the valley for about 8 miles (13 kilometers). The control of structure and rock resistance on the topography is well shown. Within the bounding faults the structure of the rocks is synclinal, and the route follows the outcrop of the Kittatinny limestone along the southeastern limb of this fold. To the west the hills are formed of younger and more resistant Martinsburg shale, which crops out along the axis of the syncline, and beyond the shale ridge the lowland on the northwest side of the valley is underlain by Kittatinny limestone forming the other flank of the syncline.

19. *Washington.*—From Musconetcong Valley the route turns southwest through a low divide to reach Washington, New Jersey. Here we are on the floor of another of the series of northeast valleys, eroded on infaulted or infolded weak sediments, which give diversity to the Reading prong of the New England Upland.

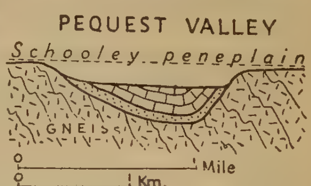


FIGURE 17.—Structure section of Pequest Valley

20. *Scott Mountain wind gaps.*—From Washington the route turns toward the northwest and affords views of the remarkable series of wind gaps cut deep into the crystalline mass of Scott Mountain. The manner in which the axes of some of these gaps converge toward the southeast seems to indicate that they were formed by tributaries of a stream flowing in that direction.

21. *Pequest Valley.*—The road passes through Van Nest Gap, the lowest of the series, into Pequest Valley (fig. 17), which, like

the German and Musconetcong Valleys, is eroded on Paleozoic sediments dropped below the Schooley level. Here the lowering of the sediments was due entirely to folding, and the synclinal structure is not broken by faults. The presence of these infolded weak sediments has allowed the development of subsequent streams, which have beheaded the southeastward-flowing superposed consequents, thus giving rise to the series of wind gaps in Scott Mountain.

22. *Buttzville.*—We leave Pequest Valley through a small water gap cut by Pequest River in the last ridge of the crystalline rocks. Just south of Buttzville a road cut exposes pre-Cambrian limestone, unconformably overlain by sandstone and shale (Hardyston), which grades upward into limestone (Kittatinny), the whole overlain by Wisconsin glacial drift. North of Buttzville the hills of the Wisconsin terminal moraine are visible.

23. *Bridgeville.*—In Jenny Jump Mountain, north of Bridgeville, the gneiss is overthrust toward the northwest on a low-angle fault plane, in such manner as to rest directly upon the Kittatinny limestone and the Martinsburg shale. Here the route leaves the crystalline rocks and enters a new physiographic region, the Great Valley subdivision of the Newer Appalachian province. The Great Valley owes its existence to the presence of weak early Paleozoic sediments, and for a number of miles we shall be traveling on either the Cambro-Ordovician Kittatinny limestone or the Ordovician Martinsburg shale. In a broad way the structure is monoclinal with a northwesterly dip, and the older limestone crops out along the southeast side of the Great Valley; but close folding introduces minor complications.

Glimpses of the Delaware Water Gap in Kittatinny Mountain are obtained as the road continues west and then north into the valley of the Delaware River. The even sky line of Kittatinny Mountain at an altitude of about 1,600 feet (490 meters) is believed by some to represent an erosion surface higher and older than the Schooley peneplain, called the Kittatinny peneplain. Lower levels on the same mountain have been correlated with the Schooley, but it seems doubtful whether two erosional surfaces on the ridge tops can be distinguished, and the sky line of the mountain is assumed to represent the Schooley peneplain.

24. *Delaware Water Gap.*—On entering the Delaware Water Gap we pass into a new subprovince. The northward-dipping Tuscarora conglomerate forming the main precipices on the south face of Kittatinny Mountain is of Silurian age and is the oldest of several beds of sandstone or conglomerate which, together with interbedded less resistant rocks, were folded, peneplained, uplifted, and dissected, to form a series of parallel ridges and valleys known as the Ridge and Valley belt of the Newer

Appalachian province. (See fig. 9.) This belt occupies the northwest half to two-thirds of the province from New York to Alabama. There is no indication of major faulting or other structural weakness transverse to the bedding at this point, and the Delaware Water Gap, like most if not all of the other gaps of the region, is believed to have resulted from superposition of a consequent stream flowing southeastward on a coastal plain overlapping the Fall Zone peneplain at some unknown level well above the crest line of the present mountain.

Thus far the only important ridge makers with which we have had to deal have been intrusive or extrusive trap sheets and the pre-Cambrian crystalline rocks. In the Newer Appalachian province the three major ridge makers are the combined Tuscarora and Clinton conglomerate and sandstone, the Pocono sandstone, and the Pottsville conglomerate. The relations of these formations to other beds involved in the folding will be apparent from the following table:

Geologic column for eastern Pennsylvania

Period or system	Group or formation	Character	Usual geomorphic expression
Pennsylvanian.	Coal Measures.	Coal beds, shales, and sandstones.	Valleys.
	Pottsville.	Gray sandstone and conglomerate of white quartz pebbles; some coal seams in upper part.	Major ridges.
Mississippian.	Mauch Chunk.	Red shales; some thin sandstone layers.	Valleys.
	Pocono.	Gray sandstone.	Major ridges.
Devonian.	Catskill.	Red and gray sandstone and shale.	Valleys and minor ridges.
	Chemung.	Reddish and gray shale.	Valleys.
	Portage.	Greenish shale.	
	Hamilton.	Gray flaggy sandstone and sandy shale.	Minor ridges.
	Marcellus.	Black shale and some fine gray sandstone.	Valleys.
	Onondaga.	Gray cherty limestone.	
	Esopus.	Gray sandy shale or grit; also known as "cauda-galli" grit.	
	Oriskany.	Light-brown to whitish sandstone, pea conglomerate, and some limy beds.	Minor ridges.
	Helderberg.	Gray limestone, shale, and limy shale.	Valleys.

Geologic column for eastern Pennsylvania—Continued

Period or system	Group or formation	Character	Usual geomorphic expression
Silurian.	Poxono Island.	Gray-green sandy shale and some limestone.	Valleys.
	High Falls.	Interbedded red and green shales and sandstones with white sandstones in upper part.	
	Clinton.	Brown and reddish sandstone and shale.	Major ridges.
	Tuscarora.	Massive gray sandstone and conglomerate of white quartz pebbles.	
Ordovician.	Martinsburg.	Greenish, yellowish, brown, or black shales and sandstones, in places altered to slates.	Valleys (Harrisburg level).
Cambrian.	Kittatinny.	Gray or bluish limestone.	Valleys (Somerville level).
	Hardyston (Chickies).	Soft gray sandstone or hard whitish quartzite.	Variable.
Pre-Cambrian.		Mostly gneisses and schists; altered sediments with interbedded volcanic rocks and intrusions of granite and other rocks.	Major ridges and plateaulike uplands.

The Tuscarora sandstone and conglomerate (figs. 18 and 19) is the first ridge maker to be encountered and the lowest member of the stratigraphic series of this area involved only in the later Paleozoic folding. The Martinsburg shale, immediately below, was apparently folded during earlier disturbances. Resistant Clinton sandstones immediately above the Tuscarora not only help in upholding the Tuscarora ridges but may themselves form the ridge crests in places.

The northwest dip of the Tuscarora is readily observed as we proceed up the gorge. The transitions from gray Tuscarora to brown or red Clinton, then to red and gray High Falls sandstone and shale, are noted. Minor folds are numerous, and the fairly prominent Kemmererville anticline (faulted) is seen where cut in section by the river. Slaty cleavage commonly cuts the bedding at high angles and exhibits the usual relations to the folding. In places the walls of the gorge show grooves and striae, believed to be the work of a tongue of Wisconsin ice descending the gorge.

25. *Delaware Water Gap Village.*—Near the northern exit from the gap brownish sandstone and shale probably represent part of the Poxono Island formation, although not typical in color. The route next crosses Cherry Valley, eroded by a small subsequent stream on the weak zone formed of Poxono Island shales and Helderberg limestone. Valley fill conceals the contact between these two formations.

26. *Godfrey Ridge.*—On the north side of Cherry Valley the road ascends obliquely the south slope of Godfrey Ridge. As revealed by the sketch map (fig. 18) and geologic section (fig. 19), this ridge is a minor anticline, overturned toward the northwest in the manner typical of Appalachian folds. Still smaller wrinkles cut obliquely across it and affect the topography of the ridge crest. As we ascend the highway cuts reveal first the top of the southward-dipping Helderberg limestone with typical fossils. This is overlain by the massive Oriskany sandstone, which dips south along the highway and forms cliffs in the woods above the road. Beyond the Oriskany the next exposures are of Esopus grit. This is seen all along the road nearly to the crest of the ridge and then again down the northern slope. The underlying Oriskany does not again come to the surface where we cross the ridge, the conditions represented in the geologic section being found a short distance to the east.

27. *Mount Michaels Creek Valley.*—At the road fork at the north base of Godfrey Ridge the cherty Onondaga limestone is exposed, stratigraphically overlying the Esopus but overturned toward the north so as to dip under it into the ridge. Farther

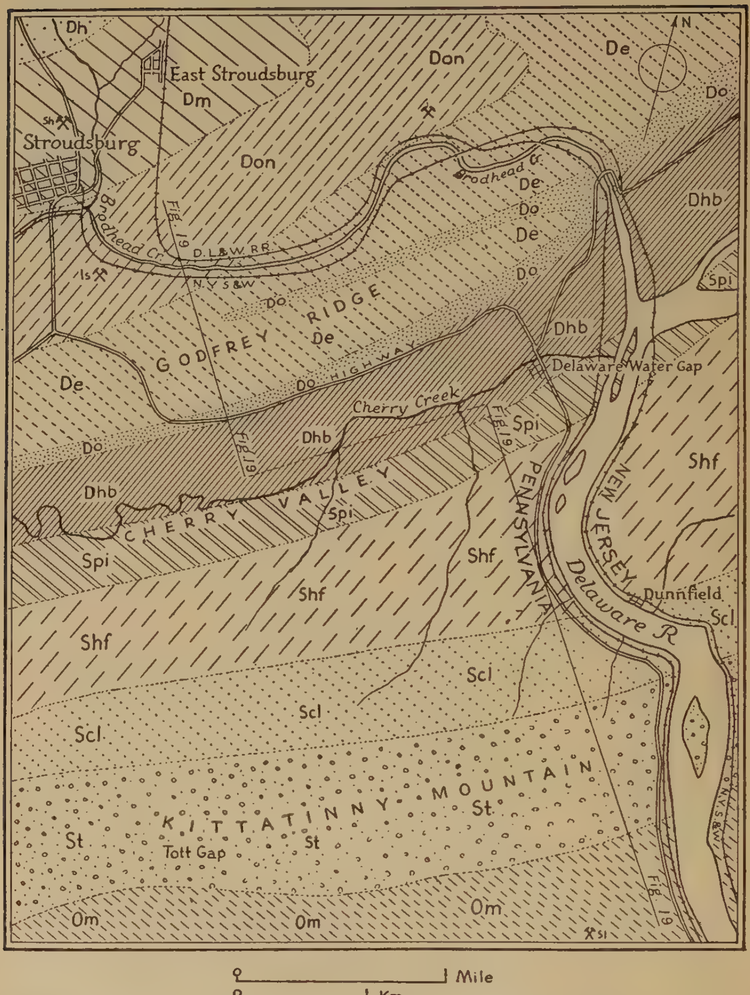


FIGURE 18.—Sketch map of Delaware Water Gap-Stroudsburg area. (After Bradford Willard, Pennsylvania Geological Survey.) Devonian: Dh, Hamilton sandstone; Dm, Marcellus shale; Don, Onondaga limestone; De, Esopus grit; Do, Onondaga sandstone; Dhb, Helderberg limestone. Silurian: Spi, Poxono Island shale; Shf, High Falls shale; Scl, Clinton sandstone; St, Tuscarora sandstone. Ordovician: Om, Martinsburg shale

north the next higher formation, the Marcellus shale, underlies much of the lowland.

28. *Stroudsburg.*—Quarries for crushed stone have been opened in the Marcellus shale, which forms the bluffs north of Stroudsburg. The beds here are interesting because they are highly fossiliferous, a rare condition for this formation.

Third day.—STROUDSBURG TO POTTSVILLE (about 100 miles, or 160 kilometers)

Luncheon at Mauch Chunk. Partial section across and along Appalachian folds. Study of the type wind gap, slate quarries, pitching asymmetric syncline, and anthracite basin.

29. *Snydersville.*—Stroudsburg is some distance north of the Wisconsin terminal moraine. Continuing southwestward, the route soon enters an area of kame and kettle topography east of Snydersville. Southwestward from points beyond Snydersville may be obtained excellent views of Wind Gap. (See No. 32, below.)

30. *Sciota.*—Excellent kettle holes in glacial deposits are to be observed a few miles beyond Sciota, but we soon pass beyond the limit of Wisconsin glaciation.

31. *Saylorsburg.*—Here the route passes through a wind gap in one of the minor ridges, presumably cut by the same stream that once flowed through the big Wind Gap, farther south.

32. *Wind Gap.*—This type example of a geomorphic feature common in the Appalachians is said to have received its name from the cold winds that often blow through it from the

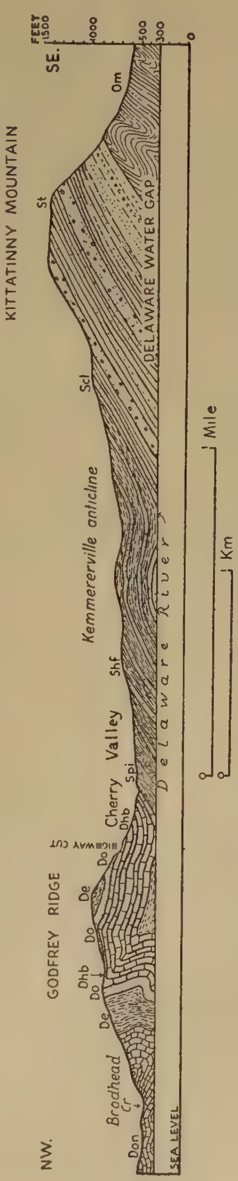


FIGURE 19.—Geologic section from Delaware Water Gap through Godfrey Ridge. (After Bradford Willard, Pennsylvania Geological Survey.) For explanation of symbols see Figure 18

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north. The bottom of the gap is at an altitude of 981 feet (299 meters); the crest of Blue Mountain (Kittatinny Mountain), representing the Schooley peneplain, ranges from 1,500 to 1,700 feet (460 to 520 meters). As is true in many others of the wind and water gaps of the Appalachian region, the crest of the ridge slopes at an angle of 2° or 3° toward the top of the gap for a considerable distance on each side. The slopes toward the gap are thought to be profiles of the very flat valley through which the streams were flowing on the Schooley peneplain. The presence of the gap in the bottom of this very faint sag in the mountain crest indicates that the streams were superimposed across the ridges from a surface earlier than the Schooley and

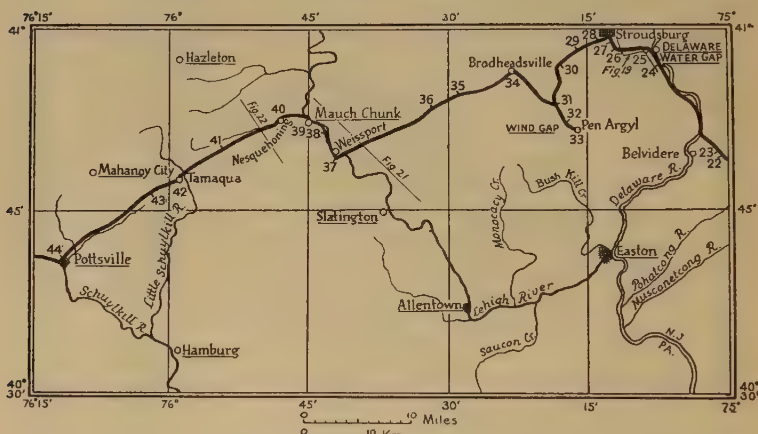

FIGURE 20.—Route map, third day

maintained their position throughout the Schooley cycle. Had the streams been superimposed directly upon the Schooley surface from an immediately overlying cover, their gaps would show no relationship to depressions in the Schooley surface. For this and other reasons the Fall Zone peneplain, with its Coastal Plain cover, is thought to have extended inland over this area, the streams having been superimposed upon it rather than upon the Schooley surface. The southeast course of the upper Susquehanna River (North Branch) might, if prolonged, pass through the gaps to join the southeast course of the lower Delaware. It is possible, therefore, that the Saylorsburg gap and Wind Gap represent traces of one of the master southeastward-flowing superposed consequents, now dismembered through capture by subsequent streams working headward along belts

of weak rock. The present depth and size of the gaps may measure erosion by the diminished consequent, after its headwaters had been led off to the Susquehanna.

From the floor of the gap the route descends southward to the Harrisburg peneplain in the Great Valley. The peneplain surface is underlain by Martinsburg shale of Ordovician age, which here constitutes one of the slate-producing sections of the United States.

33. *Pen Argyl.*—At the Albion and Parsons slate quarries close folds in the Martinsburg formation are cut across by well-developed slaty cleavage. Slate of excellent quality for school blackboards and billiard tables is obtained, as well as roofing slate.

Retracing the route through Wind Gap and Saylorsburg, the course then leads northwest across the nose of a westward-pitching syncline, plainly indicated on the topographic map but not easily recognized in the field.

34. *Brodheadsville.*—This village is in a broad, flat-floored valley eroded on weak Devonian beds (Marcellus, etc.) exposed in the core of an asymmetric anticline. The topography reveals the curious fact that the anticline here has its steeper limb on the south, while farther west the northern limb is the steeper. South of the valley moderately resistant beds (probably Hamilton and overlying formations) in Weir Mountain descend into the same syncline crossed a few miles farther back.

35. *Kresgeville.*—The flat floor of the anticlinal valley east of Kresgeville suggests a lacustrine plain, but so far as the geomorphic features are concerned there seems no necessity for inferring the former presence of a lake. Erosion of a very flat valley floor on weak shales, followed by deposition of normal flood-plain or glacial outwash gravel, would seem fully competent to explain the unusually level surface of the plain. A mile east of Kresgeville low hills rising from the plain expose rudely bedded shale fragments somewhat resembling a delta deposit but better explained as of subaerial origin.

West of Kresgeville the route ascends obliquely the south rim of the anticlinal valley, which is likewise the north rim of the synclinal mountain held up by moderately resistant beds (Hamilton and Catskill?). To weaker shales (Portage and Chemung?) between these formations appears to be due the double rim which in places characterizes the borders of the syncline.

36. *Trauchsville.*—From the upland crest, just north of Trauchsville may be seen to the north, beyond the anticlinal valley and its irregular monoclinal northern rim, the high scarp of the Pocono Plateau, held up by the very resistant Pocono sandstone and representing the northern extension of the Al-

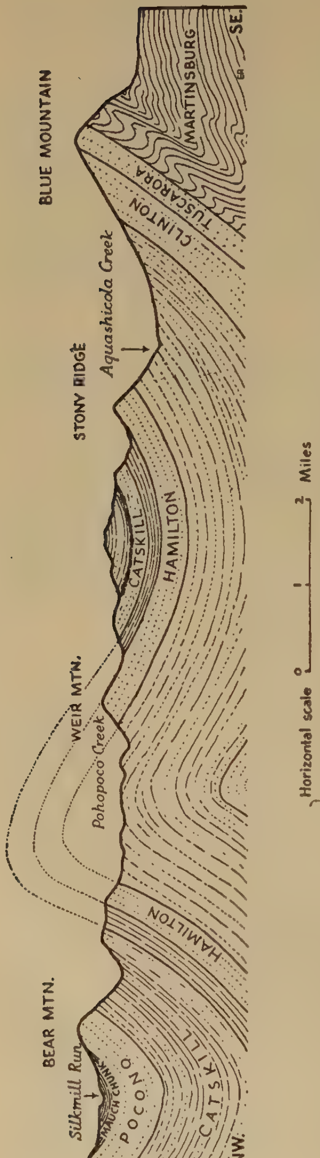

Figure 21.—Generalized section from Bear Mountain to Blue Mountain east of Weissport

legheny Front (the escarpment marking the boundary between the Newer Appalachians and the Appalachian Plateau). Southward the view is across the upland of the synclinal mountain to Little Gap, another beautiful wind gap cut in the Tuscarora conglomerate of Kittatinny Mountain, here called Blue Mountain. About a mile west of Trauchsville we may look southward along the valley of Hunter Creek, which flows directly toward Little Gap as if it were the shrunken remnant of the greater southeastward-flowing river that carved this wind gap.

The route continues westward just inside the northern rim of the synclinal mountain, descends the valley of Bull Run, a subsequent stream eroded on weak shales between the more resistant formations, and debouches into the anticlinal valley 2 miles east of Weissport.

37. *Weissport.*—Here the form of the anticlinal valley is changed. Its floor, near the master stream of the region (the Lehigh River), is deeply dissected, a work not yet accomplished by the headwaters of Pohopoco Creek in the Kresgeville-Brodheadsville area. The north side of the anticlinal valley is no longer bounded by an irregular cuesta or monoclinal ridge, with flattening dips running in under the Pocono Plateau. Instead of being at the transition

from folded mountains to plateau, we are here in a fully folded area, even the resistant Pocono to the north being warped into a prominent syncline. (See fig. 21.) The north wall of the anticlinal valley is now a double-crested ridge, of nearly vertical beds, the inner ridge being composed of the resistant formation (Hamilton?) observed in the scarp forming the south wall of the valley, and the outer or northern ridge, called the Indian Hills, consisting of the same formation (Catskill?) which gave the secondary or inner rim on the synclinal mountain farther south.

Crossing the Lehigh River at Weissport, the route turns northward through the steeply dipping northern limb of the asymmetric anticline.

38. *Mauch Chunk Gorge.*—We have risen in the stratigraphic scale to a new formation, the resistant Pocono sandstone, one of the major ridge makers of the region. It is folded into a syncline (fig. 21), and we are traversing the south limb of this fold.

The Lehigh River here flows in well-developed intrenched meanders, a pattern which may have been acquired on the Schooley peneplain and then incised and preserved in the resistant Pocono sandstone. But the general southeast direction of flow may well date far back to a time when the Coastal Plain reached far inland over this region, covering the Fall Zone peneplain, which beveled the folds at an altitude now high above the present mountain tops, and thus assuring superposition of the southeastward consequent drainage across the underlying structure.

39. *Mauch Chunk.*—This is the type locality for the next higher important member in this part of the Paleozoic series, the Mauch Chunk shales. The influence of this "valley maker" on topography is quickly apparent. Toward the east there opens up a curious basin, like the inside of the bow of a boat, a closed valley end, often called a "cove" in the Appalachian region. This is the east end of a syncline forming one of the major anthracite basins of Pennsylvania, the axis of which we shall follow southwestward for many miles. The basin, rising toward the east, is the emerging hard shell of the folded Pocono trough, from the extreme tip of which the soft core of Mauch Chunk shale has been washed out.

Crossing the axis of the syncline the route turns westward along the subsequent valley eroded by Nesquehoning Creek on the belt of weak Mauch Chunk shales that lies between the unbreached anticline of Pocono sandstone forming Broad Mountain on the north (fig. 22) and the trough of Pottsville conglomerate forming the core of the syncline on the south.

40. *Nesquehoning.*—Here the route turns south through the northern rim of the Pottsville Basin and then turns west along the axis of the fold. An open pit gives a first view of the anthracite workings and affords opportunity to examine a small faulted anticline or wrinkle in the floor of the main syncline.

Part of the Pottsville formation is coal bearing. The true "Coal Measures" come next above and are exposed for miles to the southwest, toward Pottsville. Because they are weak they are usually preserved only in synclinal troughs of the resistant Pottsville conglomerate. Even in such protected positions they have suffered much erosion and are commonly reduced below the level of the inclosing outcrops of Pottsville. Thus the coal is found in topographic as well as structural basins. The depression which we shall follow southwest, with the high

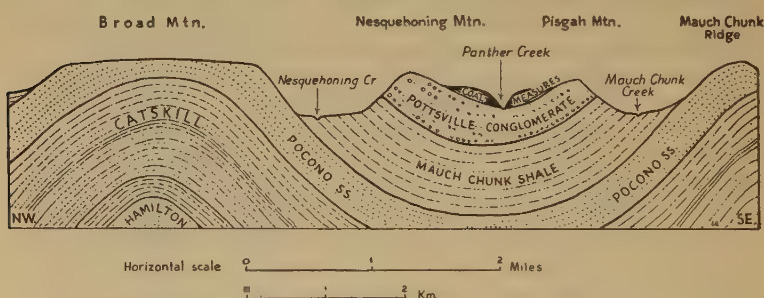

FIGURE 22.—Generalized section from Broad Mountain to Mauch Chunk Ridge, near Nesquehoning

borders of the upturned Pottsville conglomerate almost everywhere forming the sky line, is one of the most productive coal fields of the Appalachian region.

The route continues westward along the axis of the basin, past Lansford and Coaldale.

41. *Coaldale.*—Here the big colliery, the great culm piles (waste from the coal mines), and the homes of the workmen give the typical aspect of the coal-mining town. Near by are settling basins, designed to keep silt and coal débris from being carried into the streams. Some streams are overloaded and have aggraded their valleys to depths of 15 to 20 feet (4.5 to 6 meters).

The basin is full of minor wrinkles, like that observed near Nesquehoning, giving dips in all directions. As the syncline plunges toward the southwest the overturning of the folds of this region toward the northwest causes southerly dips to prevail at the surface on both sides of the basin.

42. *Tamaqua.*—This locality presents evidence that the present pattern of Appalachian drainage is not due to normal readjustments of consequent streams eroding the folds in successive cycles. The alinement of three great water gaps in a northwest-southeast direction across both limbs of the fold is not readily explicable as the product of normal stream dissection of a syncline. But the phenomenon is a necessary consequence of the theory that major southeastward-flowing streams were superposed from a coastal-plain cover resting on a peneplain that effectively beveled the folds.

43. *Tuscarora.*—North and south of the town of Tuscarora are wind gaps (well shown on the map of the Mahanoy quadrangle but not seen to advantage from the highway) which bear witness to former southeast drainage, long ago diverted by stream capture.

44. *Pottsville.*—Passing other towns and villages dependent upon the coal-mining industry, and approaching the south side of the synclinal basin, the route enters Pottsville. Here the syncline is broadest, and the Coal Measures have an outcrop 3 miles (5 kilometers) wide. Pottsville, one of the chief cities of the Pennsylvania anthracite region, owes its size in part to its location directly north of the water gap of the Schuylkill River through Sharp Mountain and Second Mountain. Much of the coal from the syncline is shipped out through this gap.

In Sharp Mountain the Pottsville conglomerate dips steeply toward the south. The subsequent valley of Tumbling Run is eroded on the weak Mauch Chunk shales, and in the low hill just south are red Mauch Chunk beds, likewise dipping south. Beyond rises the high ridge of Second Mountain, in which the Pocono sandstone dips steeply south. Evidently the south limb of the syncline is here overturned toward the northwest, a condition typical of Appalachian folding.

The presence of two systems of water gaps, closely adjacent, near the junction of two streams, such as the Schuylkill at Pottsville and the West Branch just to the west, throws light on the origin of the streams. The development and persistence of closely adjacent gaps above stream junctions is difficult to explain as a product of normal adjustments of consequent streams developed on folds. But it is to be expected that when coastal-plain drainage is superposed across previously beveled folds, some stream junctions will happen to be intrenched just below the point where the two streams cross hard-rock ridge makers.

Fourth day.—POTTSVILLE TO HARRISBURG (about 90 miles, or 145 kilometers)

Luncheon at Lykens. Partial section along and across asymmetric Appalachian folds. Study of plunging anticlines and synclines; anticlinal, synclinal, and monoclinal ridges; wind gaps and water gaps; Schooley and Harrisburg peneplains.

The route continues southwestward along the axis of the gradually narrowing syncline, passing through Minersville, Llewellyn, Branch Dale, Swatara, and Newton to Tremont.

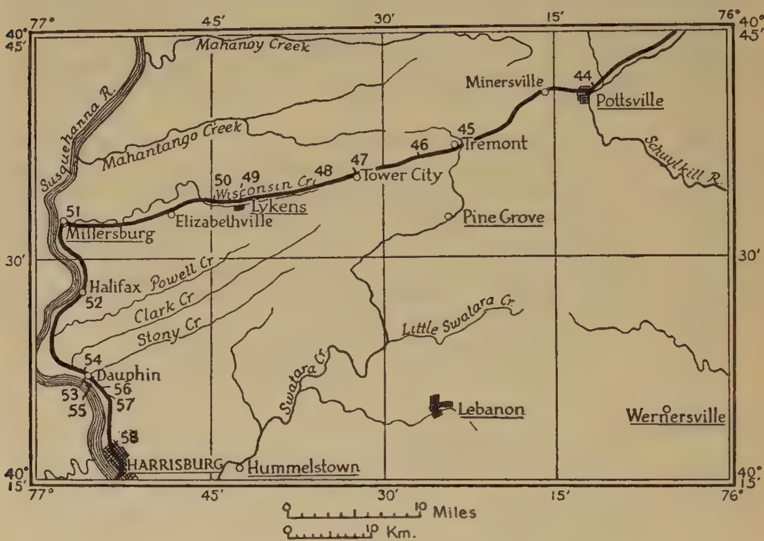

FIGURE 23.—Route map, fourth day

45. *Tremont.*—West of Tremont there is a marked change in the structure. In the axis of the syncline along which we have been traveling a small upwarp develops into a large anticline, which divides the major syncline into two minor basins extending toward the west and southwest. From Tremont the route ascends the plunging nose of the dividing anticline, here called Broad Mountain, the ascent being temporarily broken by the valley of an obliquely superposed stream, Lower Rausch Creek.

46. *Fire Tower.*—From this point in clear weather an excellent view of the ridges and valleys of the folded Appalachians may be obtained. The tower is almost on the axis of the anticline, on the resistant Pottsville conglomerate. Immediately to the west the anticline is breached by erosion, and the underlying

Mauch Chunk shales have been removed to form an anticlinal valley. Looking westward along the axis of this valley we see an arch of Pocono sandstone rising from its floor at a distance of about 6 miles (10 kilometers). This arch is a continuation, on the next underlying hard formation, of the same anticline as that on which we stand, and it is bordered on the north and south by monoclinal valleys of the Mauch Chunk shale.

From Broad Mountain the route drops downward along the southern slope of Big Lick Mountain (Pottsville conglomerate) into an anticlinal valley eroded on Mauch Chunk shale. On the north side of the road may be seen the transition between the Pottsville and the Mauch Chunk formations.

47. *Tower City.*—From Tower City we may best observe the anticlinal mountain formed by the arched Pocono sandstone plunging underground toward the east and exposed by stripping away of the weak overlying Mauch Chunk shale. It resembles the eastward-pitching Broad Mountain west of Tremont, part of the same fold exposed by stripping of weak Coal Measures.

48. *Williamstown.*—The route continues westward along Wiconisco Creek, having entered one of the monoclinal subsequent valleys eroded on the weak Mauch Chunk shale.

49. *Lykens.*—Here a visit to the mine office of the Short Mountain colliery of the Susquehanna Collieries Co. permits study of a glass model representing the true structure of the synclinal coal basin just north of the valley. Minor wrinkles and faults, as well as the eastward pitch of the fold, which carries the coal far below sea level, are well shown in this model.

50. *Short Mountain.*—From Lykens the route continues westward down the monoclinal valley (Mauch Chunk shale) of Wiconisco Creek, with Short Mountain (Pottsville conglomerate) on the north and Berry Mountain (Pocono sandstone) on the south. Three miles (5 kilometers) west of Lykens Short Mountain ends, owing to the fact that the Pottsville syncline, rising toward the west, here brought this resistant formation above the Schooley base level, permitting its removal during that long erosion cycle.

At the end of Short Mountain the route enters a broad synclinal valley formed by the union of the monoclinal Pine Creek Valley, north of the mountain, with the monoclinal Wiconisco Valley to the south, both eroded on Mauch Chunk shale. Where entered, this valley is 6 miles (10 kilometers) wide, but it narrows southwestward, owing to the pitch of the syncline. On the valley floor are many broad flats between 600 and 700 feet (180 and 215 meters) in altitude, 100 to 200 feet (30 to 60 meters) above the present streams, that are believed to be remnants of the Harrisburg peneplain.

To the north Mahantango Mountain, formed by the Pocono sandstone outcropping on the northern limb of the syncline, is cut by Pillow Gap, the water gap of Deep Creek. Wiconisco Creek may formerly have flowed northward through this gap to reach the Susquehanna River on the other side of Mahantango Mountain. If so, a stream working headward (eastward) up the subsequent valley later turned it into the present course. The possible northward course of the original stream makes this an unusual capture in the Appalachians, where most of the diversions have occurred on the north sides of their respective gaps. About 5 miles (8 kilometers) west of Pillow Gap a wind gap breaks the even crest line of Mahantango Mountain.

51. *Millersburg.*—At Millersburg the road turns southward and enters the Susquehanna water gap through Berry Mountain. In the gap the northward-dipping Pocono strata may be observed. This rock continues westward for a few miles until, at the end of the synclinal trough, it zigzags back in Mahantango Mountain. The Susquehanna is here superposed across the west end of the resistant Pocono syncline, just as it is superposed across the end of a second syncline in this same formation farther south. Had the river flowed farther to the west before turning south, it could have flowed all this distance on weak rock and thus have escaped the succession of formidable barriers. Superposition of the Susquehanna is indicated.

After passing through Berry Mountain the route enters a broad anticlinal valley eroded on the weaker Devonian formations, in the midst of which moderately resistant layers give minor ridges.

52. *Halifax.*—At Halifax the road leaves the river and runs for some distance across the considerably dissected Harrisburg level. To the south, from points at an altitude of about 600 feet (180 meters), the even sky line of Peters Mountain may be seen. The bench or shelf along the north side of the mountain is readily explained as the expression of a moderately resistant layer below the Pocono, possibly sandstone beds in the Catskill formation. Where the road passes through the water gap the southward-dipping Pocono sandstone is exposed. (See fig. 24.)

South of Peters Mountain the route enters a synclinal valley cut on the red Mauch Chunk shale, and within about a mile (1.6 kilometers) ascends from the river to the Harrisburg level, here preserved at an altitude of about 500 feet (150 meters). From points on the peneplain the west end of the Third Mountain (Pottsville) syncline presents a striking picture.

53. *Dauphin.*—Returning to the river the route follows it for 2 miles (3.2 kilometers) to Dauphin. From this point a

detour is made north 1 mile (1.6 kilometers) to the foot of Third Mountain.

54. *Third Mountain.*—On the surface of the Harrisburg peneplain at an altitude of a little over 500 feet (150 meters) may be observed outcrops of the thinly bedded Mauch Chunk shale. Third Mountain terminates abruptly in the same manner and for the same reason as Short Mountain (stop 50). The great Pottsville coal basin or syncline, which plunges underground just west of Mauch Chunk and which we entered at Nesquehoning (stop 40) and saw divide into two subordinate basins west of Tremont (stop 45), rises to the surface again to have its northern branch disappear "into the air" at Short Mountain and its southern branch similarly disappear at the west end of Third Mountain.

To the south Second Mountain, formed of the resistant Pocono sandstone, can be traced west of the river, where it is known as Cove Mountain (fig. 24), which in turn can be seen to trend westward for several miles before bending sharply back toward the northeast to become Peters Mountain. We are near the southwest end of a northeastward-pitching syncline, in which the Schooley surface, represented by the higher crests of these mountains, cuts off the Pottsville formations immediately north of us and the Pocono formation at the point where Cove Mountain doubles back.

55. *Second Mountain.*—A short distance south of Dauphin the route enters the narrow gate cut by the Susquehanna River in the Pocono formation. Outcrops of this formation are prominent in the walls of the gorge and show that the fold is overturned toward the northwest, the beds dipping about 65° S. (See fig. 24.)

56. *Little Mountain.*—Passing across the mouth of the subsequent valley eroded by Fishing Creek on weak Devonian shales, we approach the secondary crest upheld by Hamilton sandstone (fig. 24), known as Little Mountain. The beds show the effect of overturning toward the northwest, the dips being southward.

57. *Blue Mountain.*—The route passes the narrow subsequent valley eroded on the weaker formations below the Hamilton and enters the gap in Blue Mountain, where the Susquehanna River cuts through the resistant Clinton and Tuscarora formations. Beds dipping steeply southward are exposed (fig. 24), though less perfectly than in some of the other gaps. Here, as in Second and Little Mountains, the formations are overturned toward the northwest. The crests of the several ridges slope gently toward the gaps from each direction, suggesting, as mentioned before, that the Susquehanna was superposed from

a surface earlier than the Schooley and maintained its course throughout the Schooley cycle.

Blue Mountain is the southernmost ridge of the Ridge and Valley subprovince, and immediately after passing through the gap the route enters the Great Valley of the Newer Appalachian province. The highway is located on the terraced flood plain of the river.

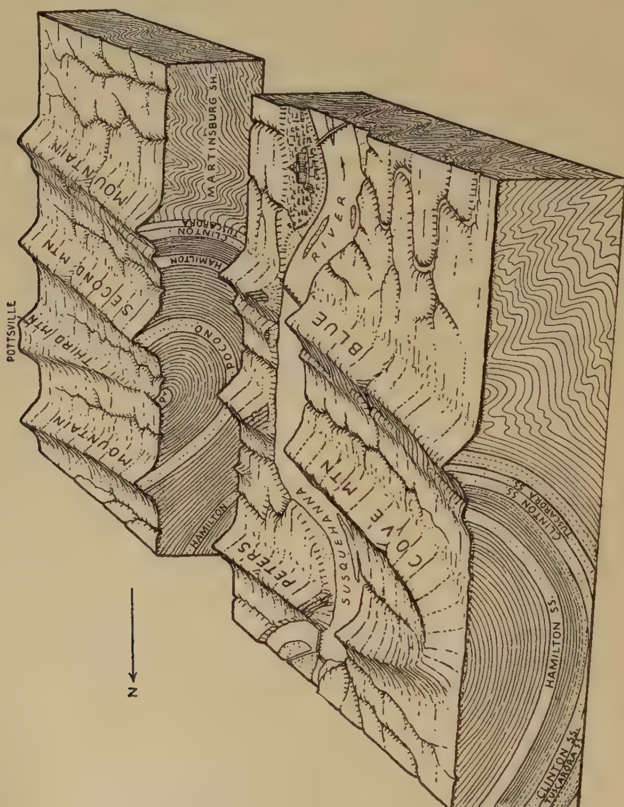

FIGURE 24.—Block diagram of overturned syncline north of Harrisburg. Pv, Pottsville. Reproduced by permission of Columbia University Press

On this section of the river dredges are often used to gather by suction coal from the bottom of the river for use as fuel in Harrisburg. This coal is transported from outcrops and culm heaps of the anthracite regions by streams entering the Susquehanna from the northeast. It sells much more cheaply than mined coal, and a large tonnage is used, even though a grate of special type is necessary for its consumption.

58. *Harrisburg*.—The capital of Pennsylvania is about 200 feet (60 meters) below the surface of the rolling upland which is called the Harrisburg peneplain, from this, its type locality. Some students of this surface think it can be divided into two or more distinct levels; but pending a definitive solution of this problem the older and simpler interpretation is followed in this guide.

Fifth day.—HARRISBURG, PENNSYLVANIA, TO HARPERS FERRY, WEST VIRGINIA (about 140 miles, or 225 kilometers)

Luncheon at Chambersburg. Traverse of the Great Valley, Triassic Lowland, and Blue Ridge. Study of Schooley, Harrisburg, and Somerville peneplains, exfoliation forms, fault-line valley, pitching synclines, superposed incised meanders, and Harpers Ferry water gap. Inspection of Gettysburg Battlefield.

59. *Toll bridge*.—Leaving Harrisburg, the route crosses the Susquehanna by a long toll bridge. At the west end of the bridge hills of Martinsburg shale rise to the level of the Harrisburg peneplain, 500 feet (150 meters) or more above the sea. We turn south and almost immediately pass outcrops of limestone to the right of the road and find ourselves on the lower level of the Somerville peneplain, at an altitude of about 400 feet (122 meters).

The route continues southwestward across the Great Valley on the level surface of the Somerville peneplain, passing scattered outcrops of limestone. Immediately to the south the higher land is formed by the Martinsburg shale, which preserves the Harrisburg peneplain at an altitude of about 550 feet (170 meters). Beyond these shale hills several summits rising 1,000 to 1,400 feet (300 to 430 meters) above sea level are caused by resistant igneous rock in the Triassic Lowland.

60. *Shepherdstown*.—About a mile northeast of Shepherdstown the road turns to the left and climbs a steep hill. The ascent is from the Somerville to the Harrisburg level, and disintegrating Martinsburg shale may be seen in the road cuts. Shepherdstown is built on the Harrisburg level, and from its southern outskirts may be had an usually significant view of the landscape. Four miles (6.4 kilometers) away toward the southwest is South Mountain, the most northern point of the Blue Ridge, which is called the Carlisle prong, from the city situated near its tip.

To the north or right of the Blue Ridge stretches away the Great Valley, limited farther north by Blue Mountain. This natural corridor, extending unbroken from Alabama to New York, was selected by the Confederate commander in chief, Robert E. Lee, for his invasion of the Northern States during

the Civil War. Immediately to the right is the marked slope separating the Harrisburg from the Somerville surface. To the left, or toward the south, is the Triassic Lowland, about 300 feet (90 meters) higher than the Somerville surface, but with many higher portions caused by resistant trap.

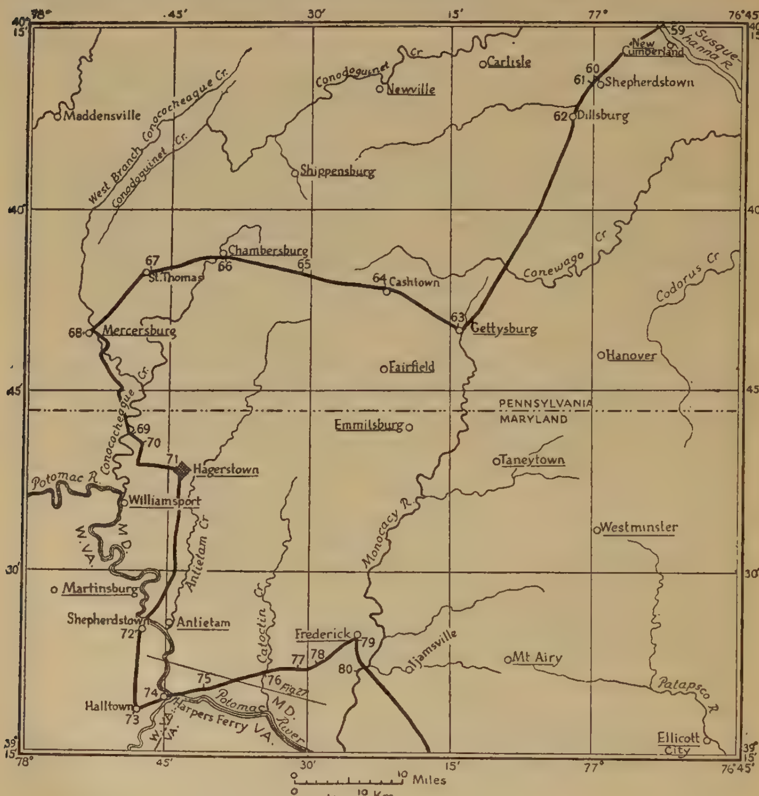

FIGURE 25.—Route map, fifth day

61. *Rosegarden.*—Here the highway crosses Yellow Breeches Creek, leaving the Great Valley and entering the Triassic Lowland. The rocks in this section of the province dip toward the northwest, against the great boundary fault which dropped them downward in that direction.

62. *Dillsburg.*—In the vicinity of Dillsburg, the next village beyond Rosegarden, we are within 1 mile (1.6 kilometers) of the foot of the Blue Ridge. The top of the ridge is believed to

represent the Schooley peneplain, but here as elsewhere later dissection has largely destroyed that surface. From Dillsburg to Gettysburg the route traverses a typical section of the Triassic Lowland. The altitudes usually range from 500 to 700 feet (150 to 215 meters), while the slopes of the low, rolling hills as a rule are gentle. The country appears poorer, the farms less prosperous, and the towns smaller and less numerous than in the Great Valley. The sandy expanses of the Triassic belt are obviously less fertile than the limestone belts of the other province.

To the west many glimpses of the Blue Ridge may be had; to the east a few points on the horizon are formed by summits in the Trenton prong of the Piedmont province, although parts of this province are even lower than adjacent parts of the Triassic belt. The southern part of the Triassic Lowland thus lies between the Carlisle and the Trenton prongs, as the northern part lies between the Reading and Manhattan prongs.

63. *Gettysburg.*—On the outskirts of Gettysburg we begin to see monuments commemorating the decisive battle which was fought here between the Union and Confederate forces on July 1, 2, and 3, 1863. The Union forces, defeated in their attempt to hold the sandstone and trap ridges west of the town, took up a strong position south of the city, on a ridge of trap curved like a fishhook. The Confederates occupied the town and Seminary Ridge, which stretches off to the southwest, parallel to and about a mile (1.6 kilometers) from the shank of the Union fishhook. The battle centered around the efforts of the Confederates to dislodge the Union army from its superior position. In this the Confederates were unsuccessful, and on July 4 they retreated westward across the Blue Ridge and down the Great Valley.

From the village square at Gettysburg, the route turns westward and climbs the eastern slope of Seminary Ridge, where a trap dike cuts the shales. This dike is traceable for 12 miles (20 kilometers) or more, northward through Oak Hill and southward beyond a point where it intersects another dike that is continuous to the Potomac. Seminary Ridge, which follows the first dike to the intersection and then the second for some distance, owes its existence to the superior resistance of the trap.

64. *Cashtown.*—Here the route crosses the fault between the Triassic Lowland and the Blue Ridge. Like the escarpment between the Triassic and the crystalline rocks in New Jersey, this is a fault-line scarp and was formed by post-Schooley erosion removing the weak Triassic sediments from the east side of the fault plane. The Blue Ridge in this region owes its prominence to the resistant qualities of the metamorphosed Algonkian lava flows and the siliceous Cambrian sediments of

which it is largely composed. From Cashtown the highway climbs steadily for about 4 miles (6.4 kilometers) to the top of a divide between east and west drainage at an altitude of about 1,410 feet (430 meters). The higher ridges range from 1,700 to 1,900 feet (520 to 580 meters) in altitude and trend, like the valleys, in a northeasterly direction, in accordance with the structure. The transverse streams causing the rectilinear valley followed by the highway seem to be subsequent upon a great transverse fault.

65. *Black Gap.*—Five miles (8 kilometers) below the crest of the divide, the road, which has been pretty constantly descending, emerges from the Blue Ridge into the Great Valley at Mount Union. North of the road the Blue Ridge is offset westward into the Great Valley for about 3 miles (5 kilometers). The topography suggests that this offset may be due to the great transverse fault mentioned above.

On this eastern border of the Great Valley sandy shale and shaly limestone, overlain by gravel wash for 3 miles (4.8 kilometers) west of Black Gap, have preserved a surface, believed to be the Harrisburg, at an altitude of 800 to 900 feet (245 to 275 meters) except near Conococheague Creek. From Stonehenge the route descends to a lower level (600 to 650 feet, or 180 to 200 meters) carved on more soluble limestones, and reaches Chambersburg.

66. *Chambersburg.*—This town lies on the lower limestone surface (presumably Somerville, although designated "Bryn Mawr" by those who recognize a larger number of erosion levels on the Atlantic slope), here only about 2 miles (3.2 kilometers) wide. Immediately to the west rise hills of Martinsburg shale preserving the Harrisburg peneplain at an altitude of 700 to 750 feet (215 to 230 meters).

Leaving Chambersburg, the road climbs quickly to the Harrisburg level on the Martinsburg shale. From the crest of the rise we may readily note the contrast between the Harrisburg and Somerville (Bryn Mawr) levels, and farther west the first ridges of the Ridge and Valley belt show the even sky line of the Schooley peneplain.

67. *St. Thomas.*—Between St. Thomas and Mercersburg fine views are obtained of Jordan and Parnell Knobs, to the north, the ends of two northeastward-pitching synclines. The resistant formation involved is the Tuscarora, here a massive white quartzose sandstone.

68. *Mercersburg.*—From this point the route turns southeastward across the floor of the Great Valley, traversing the Somerville (Bryn Mawr) level, passing through Welsh Run, and soon crossing the boundary line between Pennsylvania and Maryland.

69. *Conococheague Creek.*—This stream presents a problem of some geomorphic interest. The incised meandering valley shows the undercut and slip-off slopes typical of this type of rejuvenated stream. But of greater interest is the close coincidence between the width of the meander belt and the width of the belt of Martinsburg shale, to which the stream is almost wholly confined. The shale belt occupies a synclinal trough, and the underlying limestone comes to the surface on each side. In places the shale is a little more resistant than the limestone and stands at a higher level. Thus we have a miniature synclinal mountain, with a stream meandering lengthwise along the mountain belt but seemingly avoiding the weaker limestones on both sides.

A possible explanation is offered in Figure 26. When this stream was flowing above the Schooley base level (SB) it developed meanders on a subsequent valley eroded in Clinton shales and sharply limited by the very resistant Tuscarora sandstone or quartzite ridges. After uplift the stream cut down to the level of the Harrisburg and later of the Somerville peneplain (HS), doubtless somewhat enlarging its meanders in the process but not enough to extend far beyond the limits of the shale belt at the present level. Thus the meanders are in some places well within the shale belt, in others they cut a little way into the limestone, but in general they are concordant with the limits of the shale formation.

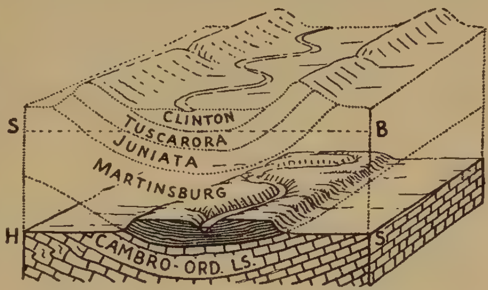

FIGURE 26.—Diagram illustrating possible history of Conococheague Creek

70. *Cearfoss.*—From Cearfoss the route leads south to Huyett, thence east to Hagerstown. The shale belt just west of the road gradually increases in altitude until the relief is very noticeable, and a prominent scarp separates the shale upland at 580 feet (180 meters) from the limestone lowland at 450 to 500 feet (140 to 150 meters). These relative altitudes do not continue over any considerable area, however.

71. *Hagerstown.*—From Hagerstown the route turns south along the Great Valley. The Blue Ridge or Carlisle prong far off to the left preserves traces of the Schooley peneplain, and at least two levels are distinguishable at most places on the valley

floor. Whether these represent the Harrisburg and Somerville levels, so widely developed farther north, or should be classed as Bryn Mawr and a later surface known as the Brandywine, is uncertain.

Passing along the western edge of the battlefield of Antietam, the route lies through Sharpsburg and reaches the Potomac River at Shepherdstown.

72. *Shepherdstown.*—The Potomac, like the Delaware and the Susquehanna, is one of the great superposed southeastward-flowing rivers of the Appalachians. Here it serves as the boundary between the States of Maryland and West Virginia. The incised meanders of the stream are very pronounced, and the undercut slope on the Shepherdstown side is notably steep. About 3 miles (5 kilometers) south of the town we get a good view of the Blue Ridge and note the even sky line representing the Schooley peneplain. About 2½ miles (4 kilometers) farther

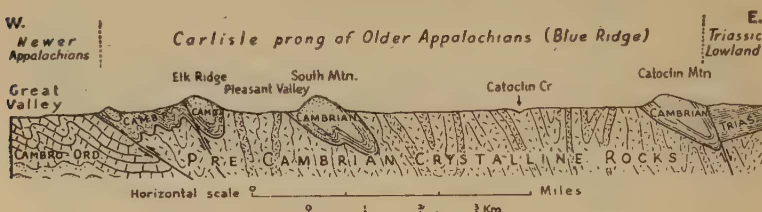

FIGURE 27.—Generalized section from the Great Valley to the Triassic Lowland north of Harpers Ferry. (After Arthur Keith, U. S. Geological Survey)

south, near the bend in the road northeast of Reedson, is a vantage point from which to view the Potomac water gap through the ridge at Harpers Ferry.

73. *Halltown.*—Here the route turns east, and just southwest of Bolivar it crosses an outlying ridge consisting of Cambrian sandstone which has been overthrust to the northwest upon the Cambro-Silurian limestones.

74. *Harpers Ferry.*—The Potomac from the northwest, after receiving its great subsequent tributary, the Shenandoah, from the southwest, leaves the Great Valley at Harpers Ferry and cuts directly across the Blue Ridge barrier. This barrier here consists of two main ranges—the Blue Ridge (locally called Elk Ridge) and South Mountain (locally called Short Hill)—and an outlying range farther east (Catoctin Mountain). Each of these three ranges is a long, narrow synclinal ridge of closely folded resistant Cambrian sandstone (fig. 27), each fold being overturned toward the northwest and resting on pre-Cambrian crystalline rocks. The pre-Cambrian rocks, mainly granite and

schist, are here less resistant to erosion than the sandstone and have been worn down to the Harrisburg (or later?) level, but the sandstone still rises well toward or even to the Schooley level.

The gap itself consists of a more gently sloping upper portion and a steep-walled inner gorge. The inner gorge may well represent rejuvenation of the stream at the time the Harrisburg (?) surface was trenched. Above the gorge proper the crest of the ridge on each side slopes gently toward the river. This might perhaps be explained as the result of a local narrowing of the sandstone belt across which the stream is intrenched, but of such narrowing the form of the ridge affords no evidence. The feature seems definitely related to the position of the Potomac River but apparently is well developed below the normal level of the Schooley peneplain and if so is not quite analogous to the gapward slopes of ridge crests already noted in the Ridge and Valley belt. Warping of the peneplain to give a transverse trough followed by the river has been suggested as one means of explaining the phenomenon.

Sixth day.—HARPERS FERRY, WEST VIRGINIA, TO WASHINGTON (about 65 miles, or 105 kilometers)

Traverse across Blue Ridge (Older Appalachians), Triassic Lowland, and Piedmont belt. Study of synclinal ridges, erosion lowlands on crystalline rocks, and correlation of peneplains.

From Harpers Ferry the route crosses the Potomac, passes through the narrow gap in the first sandstone ridge just below the junction of the Shenandoah, and for 2 miles (3.2 kilometers) traverses the subsequent Pleasant Valley developed on weak pre-Cambrian crystalline rocks (fig. 27), to reach Weverton.

75. *Weverton.*—This is the type locality for the massive Cambrian sandstone found in the three synclinal ridges of this region, which is known as the Weverton sandstone. Here the route passes through the water gap in the second ridge (South Mountain or Short Hill) and at Knoxville turns northeast across the crystalline lowland past Petersville to Catoctin Creek.

76. *Catoctin Creek.*—From a point on the Harrisburg (?) or Bryn Mawr (?) surface just west of the creek (fig. 27) may be had an excellent view of the high ridge of Weverton sandstone to the west (South Mountain), the subordinate ridge of the same formation to the east (Catoctin Mountain), and the broad crystalline lowland between the two. So far as the topography is concerned, the Antietam quadrangle might easily be mistaken for a part of the Ridge and Valley belt, with broad lowlands on shale or limestone. Yet here the lowlands are developed on

pre-Cambrian schist and granite, and we are in a part of the Blue Ridge district of the Older Appalachians, where the only highlands consist of sedimentary rock.

77. *Catoctin Mountain.*—Crossing Catoctin Creek the route runs eastward through a prominent wind gap in Catoctin Mountain. This gap (altitude 661 feet, or 201 meters) lies southeast of a prominent wind gap in South Mountain (Crampton Gap;

FIGURE 28.—Route map, sixth day

930 feet, or 283 meters), and west of Crampton Gap Elk Ridge has cut across its northern slope yet a third gap (altitude more than 1,060 feet, or 323 meters). These gaps suggest the former presence of another southeastward-flowing consequent river, superposed from the westward-overlapping Coastal Plain but less fortunate than its close neighbor, the great Potomac, in maintaining its path across the resistant sandstone barriers.

After descending the eastern slope of Catoctin Mountain, we find the Triassic Lowland in its normal position (fig. 27) just east of this last member of the Blue Ridge (Carlisle prong of the Older Appalachians), the Triassic beds again dipping northwest against the great boundary fault that runs along the eastern base of the range. Here the Triassic belt is very narrow.

78. *Feagaville.*—Before reaching Feagaville we cross a dissected bench or terrace upheld by the narrow belt of Triassic rocks, at an altitude of 400 to 460 feet (120 to 140 meters). Just to the east is a lower belt (about 300 feet, or 90 meters) developed on Cambro-Silurian limestone. Farther east the Piedmont Upland (Trenton prong) stretches away with gradually increasing altitudes, rising from 400 to 500 feet (120 to 150 meters) near the limestone lowland to 700 or 800 feet (215 to 245 meters) farther southeast. Off to the west the ridges of the Carlisle prong mark a pronounced level around 1,400 to 1,600 feet (430 to 490 meters). Thus we seem to have four distinct erosion surfaces in this area, instead of the three most easily recognizable in the Appalachians farther north.

The bench at 400 to 460 feet (120 to 140 meters) is missing northwest of Frederick, owing to the absence of the Triassic formation. Possibly an upwarp in the underlying limestones brought them high enough to be intersected by the 400 to 460 foot erosion level. When dissection of this surface began there would have been no Triassic cover to protect the limestones northwest of Frederick, which in consequence would have quickly been reduced to the lower (Brandywine?) level.

79. *Frederick.*—The town of Frederick stands on the low limestone plain. Turning south across a surface marked with a few sink holes, the route approaches a low scarp bounding the plain on the east and rising rather abruptly to the Piedmont Upland.

80. *Monocacy River.*—Immediately beyond the Monocacy River the highway enters schists of the Piedmont belt and ascends to the upland surface. Thence to Urbana and beyond there are excellent views of the remarkably even surface of this peneplain, which bevels neatly across highly inclined strata. Off to the southwest Sugarloaf Mountain, another syncline of more resistant Cambrian sandstone (Weverton), rises as a monadnock. The surface continues to rise toward Clarksburg.

81. *Clarksburg.*—Here the road is nearly 700 feet (215 meters) above sea level, and had it traversed the peneplain farther to the northeast, still higher altitudes would have been attained. Toward the southeast the surface again descends gradually. There is thus a low, broad arch of the upland surface which has been interpreted as the result of recent warping of the Piedmont peneplain.

From Clarksburg we traverse the southeastward-descending slope of the Piedmont and see many broad vistas of its much dissected but still remarkably uniform upland surface. According to some authorities this surface is marked by a succession of obscure terraces or benches that may be of marine origin, either etched on the surface of a peneplain of fluvial origin or carved by waves as incidents in fashioning a marine peneplain.

The eastern border of the Piedmont province and the margin of the Coastal Plain is reached at Washington.

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